Signal, Spectrum, and Network RF Test Equipment

Ward Silver NØAX

Overview

- An introduction to RF signal generators, spectrum and network analyzers
- Typical Features and Specifications
- Basic Use
- Buying Equipment
- Resources for using them

Definitions

- Dynamic range - difference in power between smallest detectable signal and largest signal for which device meets spec
- IMD - Intermodulation Distortion
- Jitter - random jumps in phase or frequency
- Return Loss - the amount by which reflected power is reduced below forward power

Definitions

- SINAD - SIgnal + Noise and Distortion
- SNR - Signal to Noise Ratio
- THD - Total Harmonic Distortion
- Two-Port Device - a circuit that has only two signal access points (ground can be shared)

Signal Generators

Signal Generators

- Source of RF signals similar to transmitted signals on the air (> 100 kHz, generally)
- CW, AM, and FM, primarily (not data)
- Emphasis on signal purity
- Wide power range
- Used for receiver and transmitter testing

Useful Specifications

- Frequency: 100 kHz to 500 MHz or higher
  - Synthesized, < 10 Hz resolution
- Power: -120 dBm to +10 or +20 dBm
- AM & FM Modulation
  - internal or external source
  - adjustable modulation index or deviation
- Swept output

HP8640B

Digital frequency display

Frequency

Output

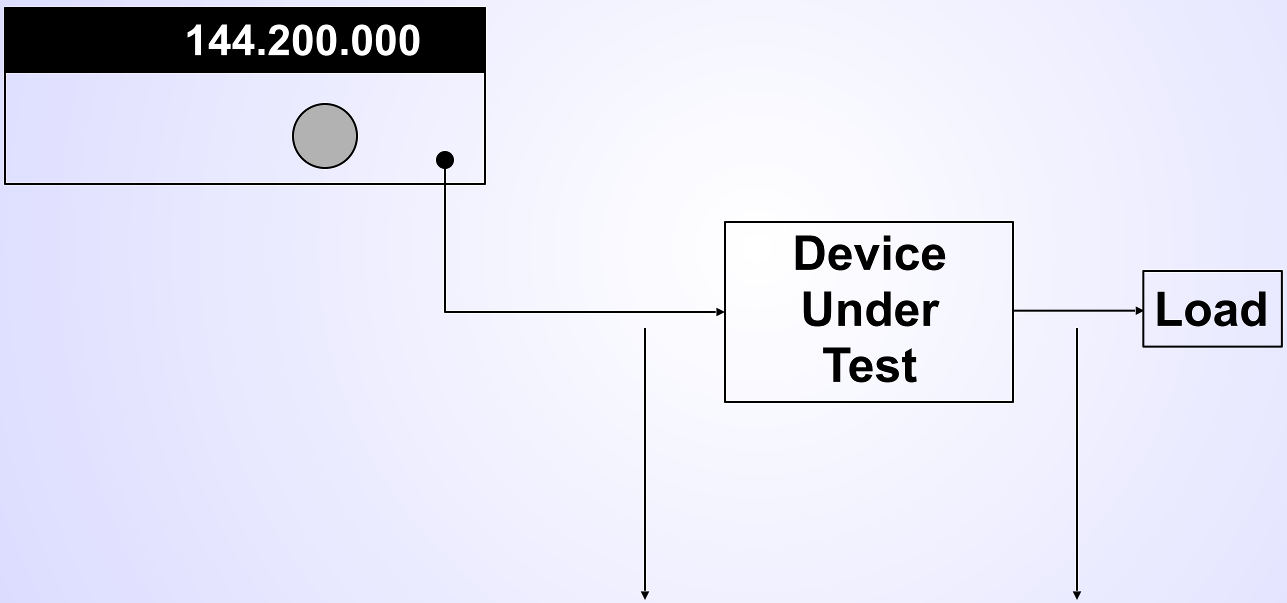
AM & FM Controls

Output level

Uses for Signal Generators

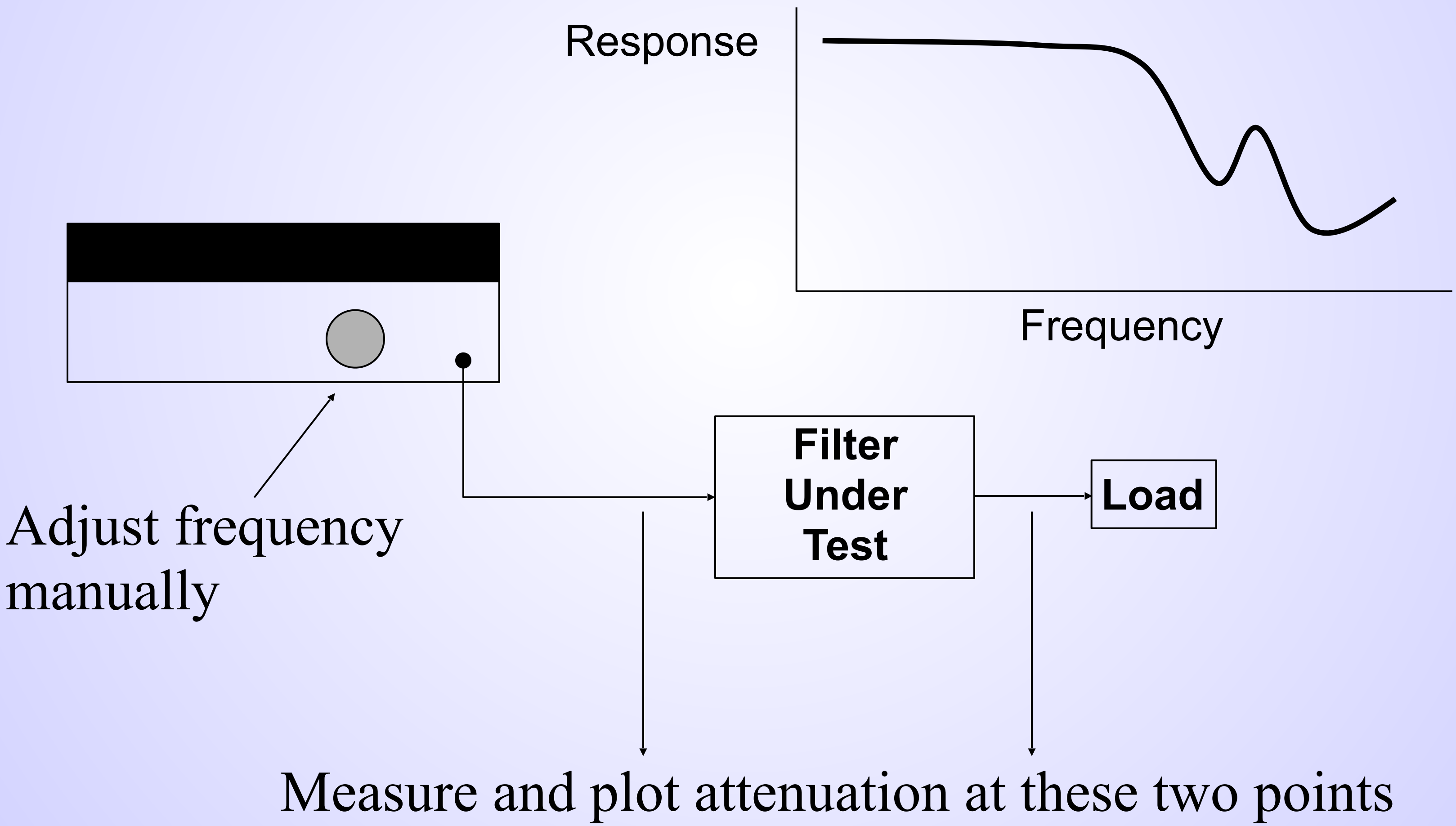
- Gain & Attenuation
- Filter Testing
- Filter Alignment
- Receiver Sensitivity
- Receiver & Transmitter Linearity

Gain & Attenuation

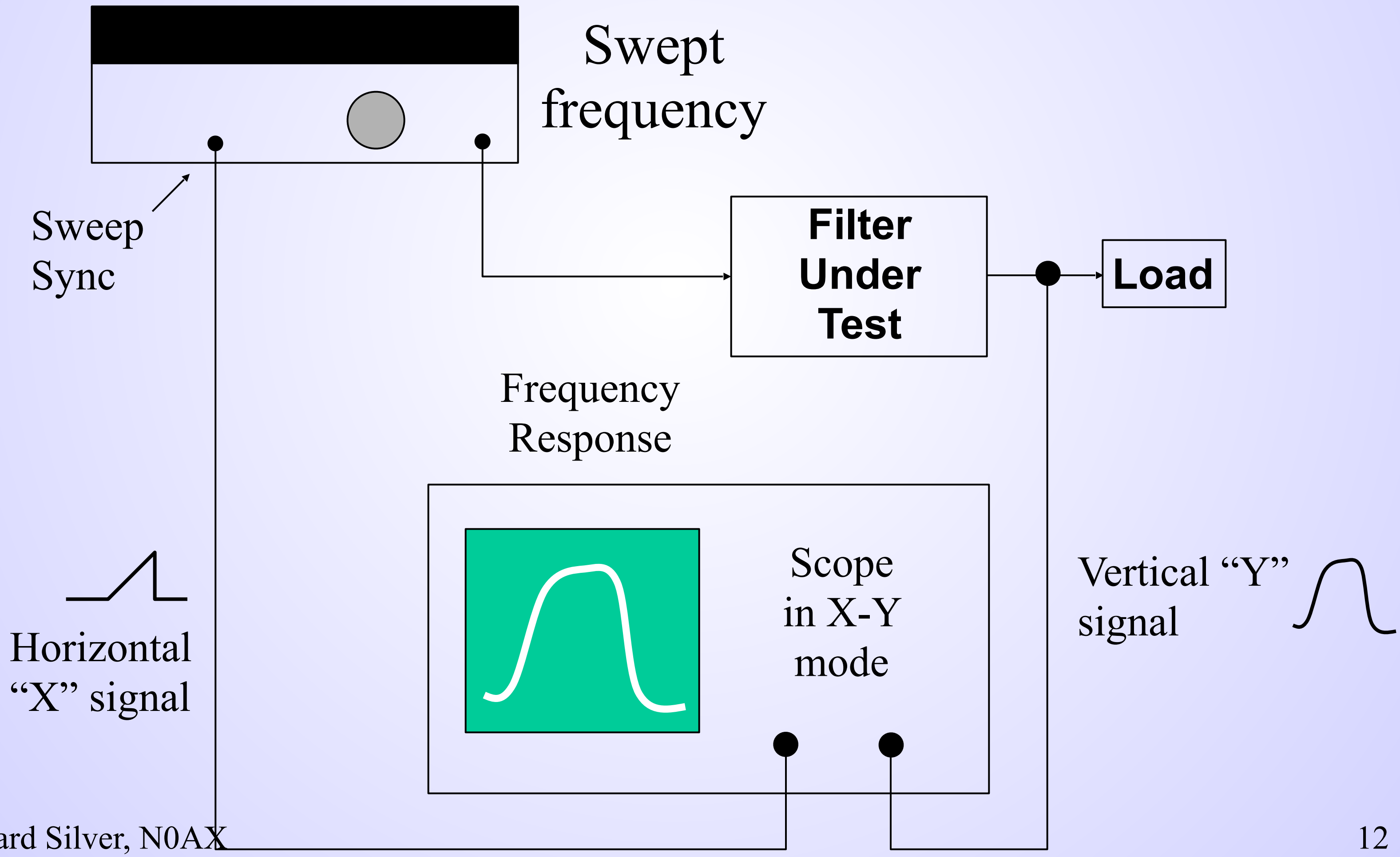


Compare power at these two points

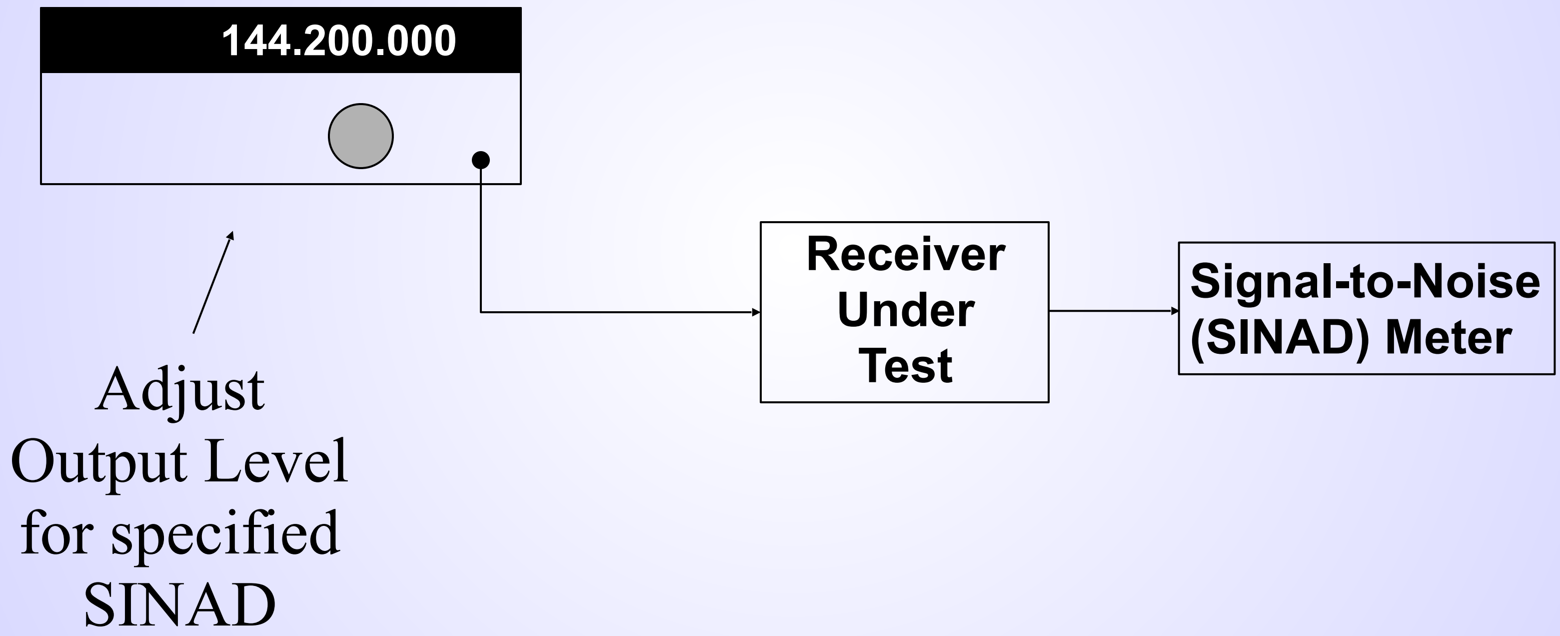
Filter Testing



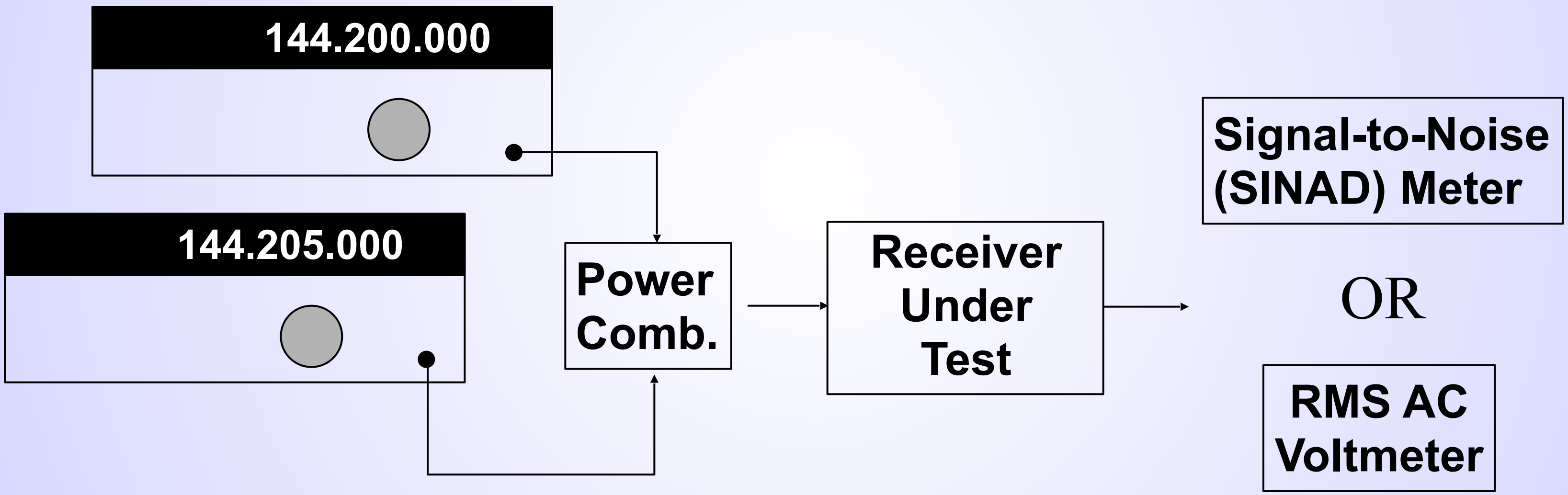
Filter Alignment



Receiver Sensitivity



Receiver & Transmitter Linearity



Measurement Caveats

- Output level errors due to load
- Excessive dc levels or backfed signals
- Signal leakage at low levels
- Noise floor and phase noise
- Frequency or phase jitter

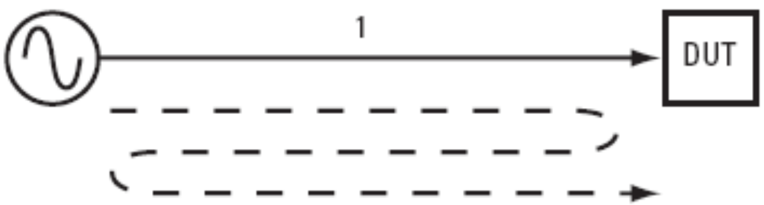
Example

Agilent Application Note 1306-1

Given: Source SWR = 1.9
Device Under Test with SWR = 1.5

Find: Mismatch error

- Before inserting an attenuator



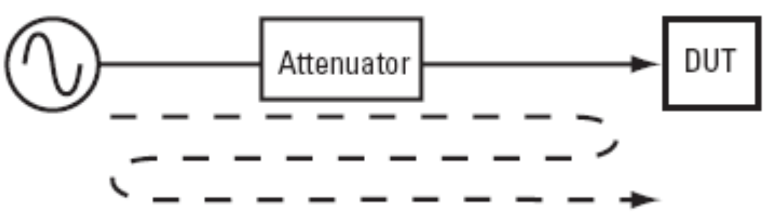
max mismatch error $\simeq \pm$ 0.52 dB

$$\rho_S = \frac{SWR-1}{SWR+1} = \frac{1.9-1}{1.9+1} = \frac{0.9}{2.9} = 0.31$$

$$\rho_D = \frac{0.5}{2.5} = 0.2$$

$$\text{mismatch error} = 20 \log [1+\rho_S \rho_D] = 20 \log [1+(0.31)(0.2)] \simeq 0.52 \text{ dB}$$

- After inserting a 10 dB attenuator with r = 0.32



max mismatch error $\simeq \pm$ 0.055 dB

$$\text{mismatch error} = 20 \log [1+\rho_S \rho_D (\text{atten})^2]$$

$$= 20 \log [1+(0.31)(0.2)(0.32)^2] \simeq 0.055 \text{ dB}$$

Emptor Caveats

- Worn or overloaded attenuators
- Unlocked, noisy oscillators
- No output or intermittent output
- Repair parts can be REALLY hard to get
- Lots of possible setting erors
- Manuals not expensive - get one!

Spectrum Analyzers

Spectrum Analyzers

- Swept frequency receivers
- Visible display
- Variable bandwidth, sweep rate
- Automated measurements
- Wide dynamic range

Useful Specifications

- Frequency: 100 kHz to 1 GHz or higher
- Noise floor: -100 dBm or better
- Maximum signal: +30 dBm
- Minimum bandwidth: <500 Hz
- Tracking generator
- Measures Δ freq and Δ power
- Portable - for field use

HP8593E

Frequency/Span/Amplitude

Operating Modes

Direct Numeric Entry

Generator Output

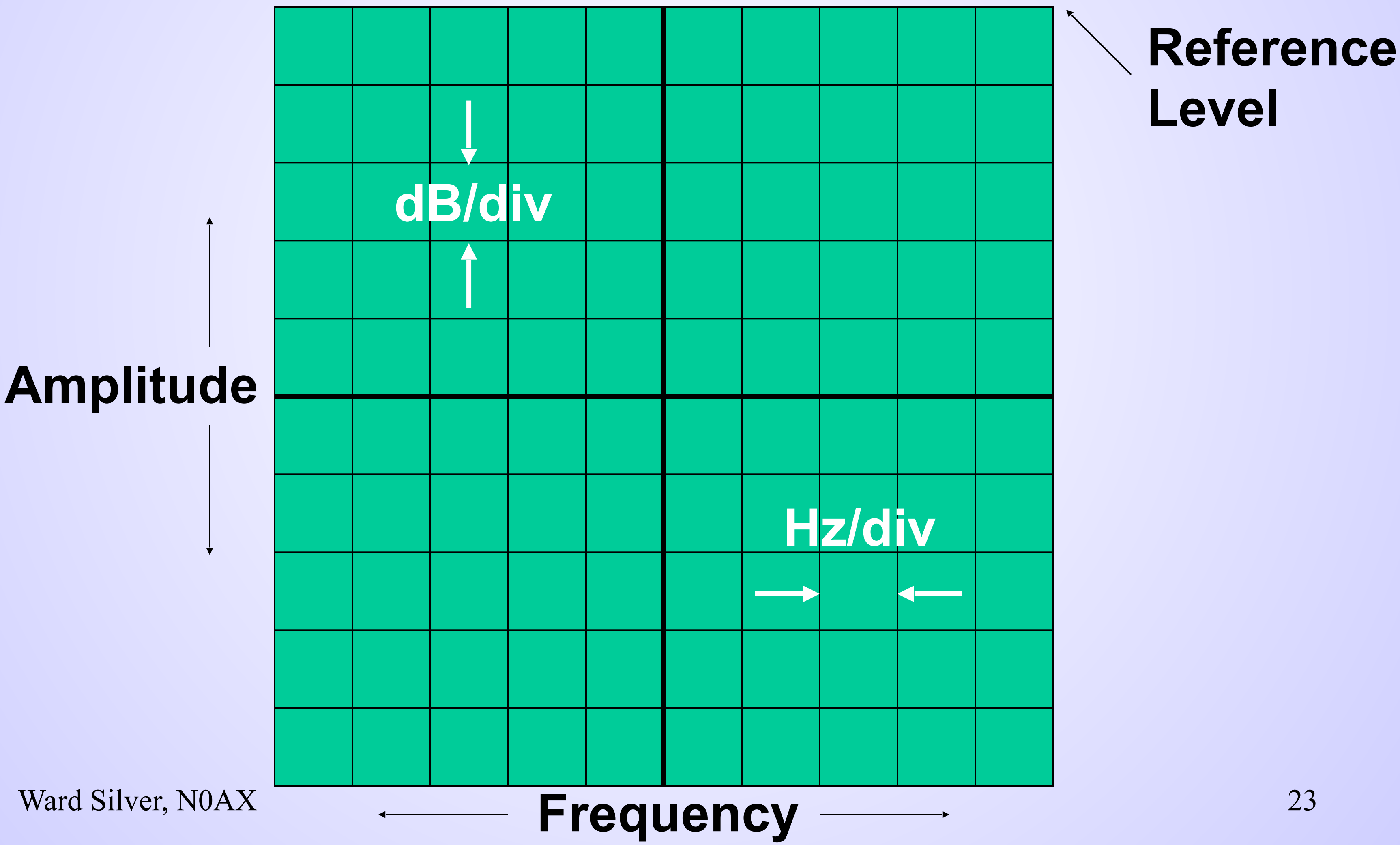
Input

Cursor & Value Control

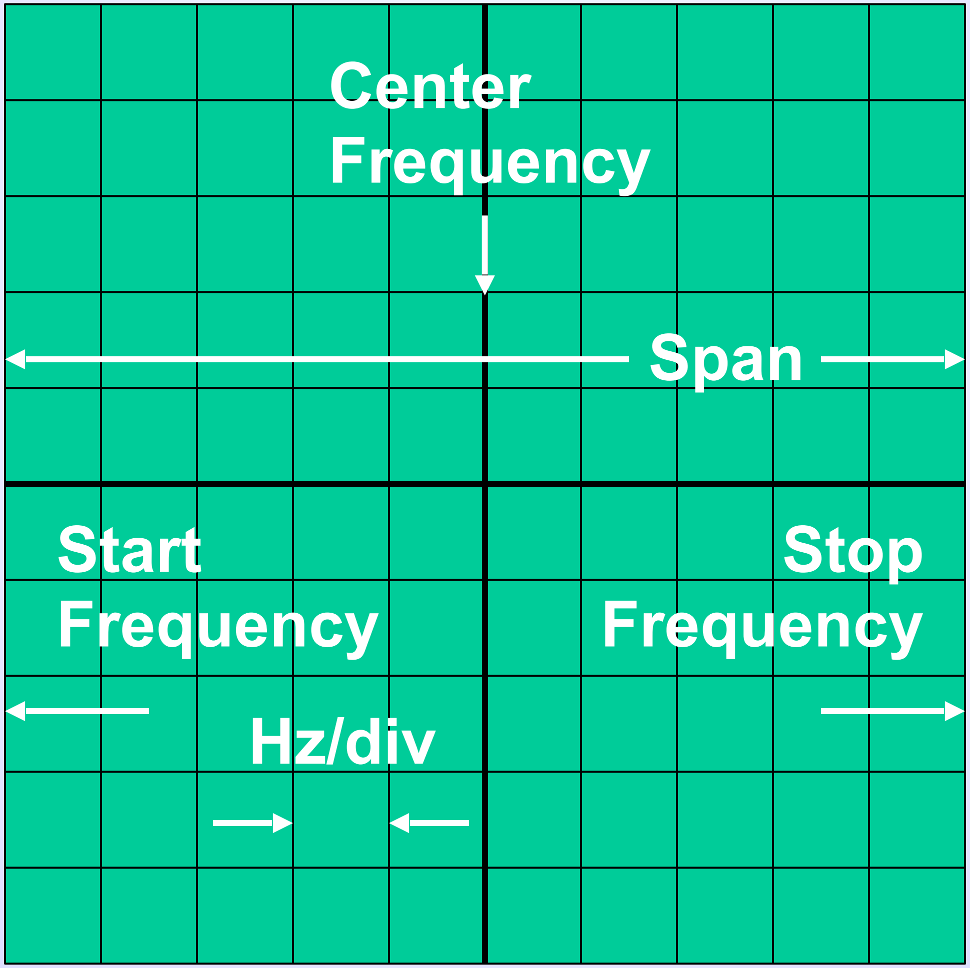
Uses for Spectrum Analyzers

- Gain and Attenuation Measurements
- Spectrum Review and Checks
- Oscillator and Transmitter Alignment
- Filter Alignment

Frequency Domain Measurement



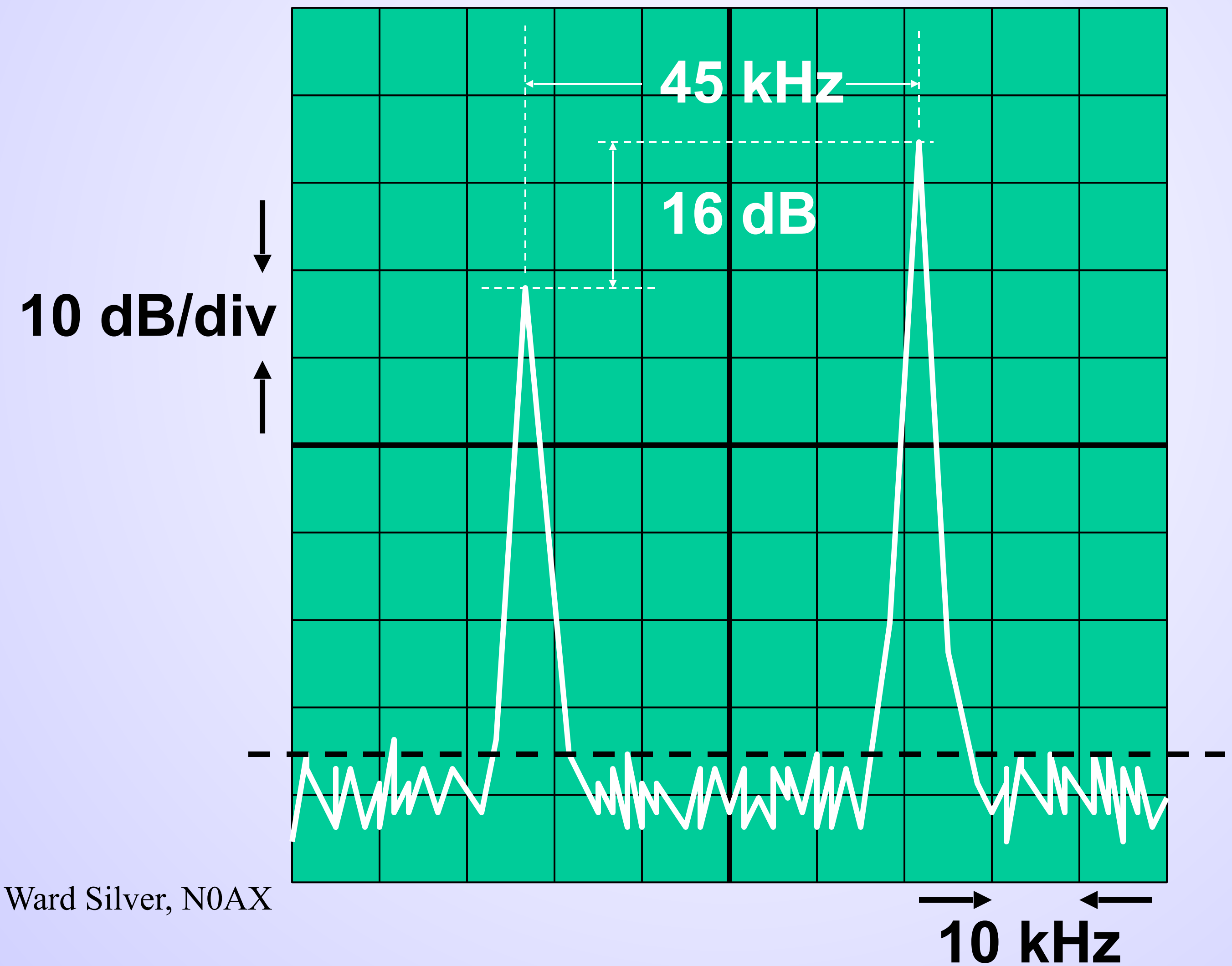
Frequency Domain Measurement



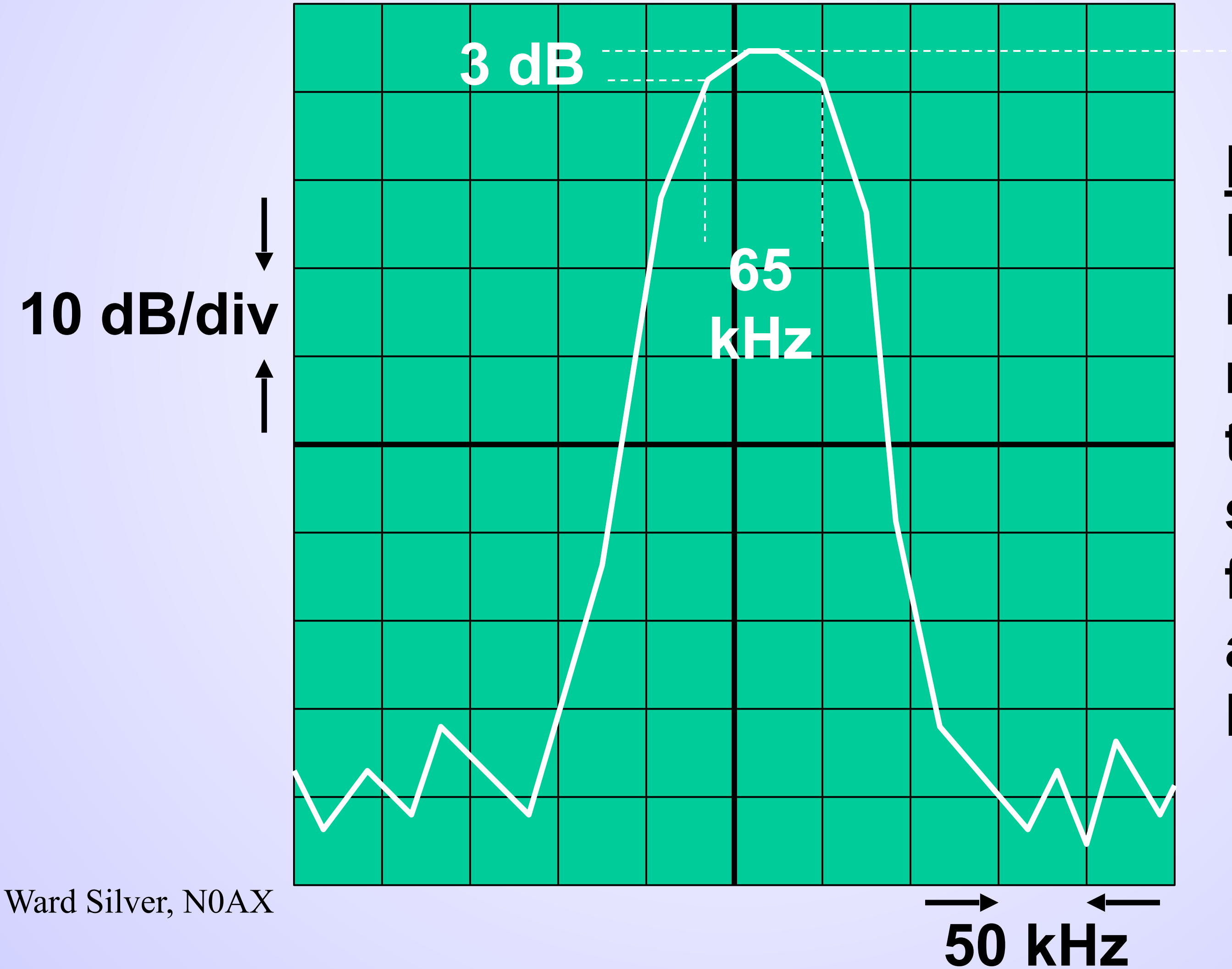
Frequency
<u>Set-up #2</u>
Center Freq
Span (Hz)
(Hz/div is calculated)

Frequency
<u>Set-up #1</u>
Hz/div
Start Freq
Stop Freq
(Center Freq is calc'd)

Frequency Domain Measurement

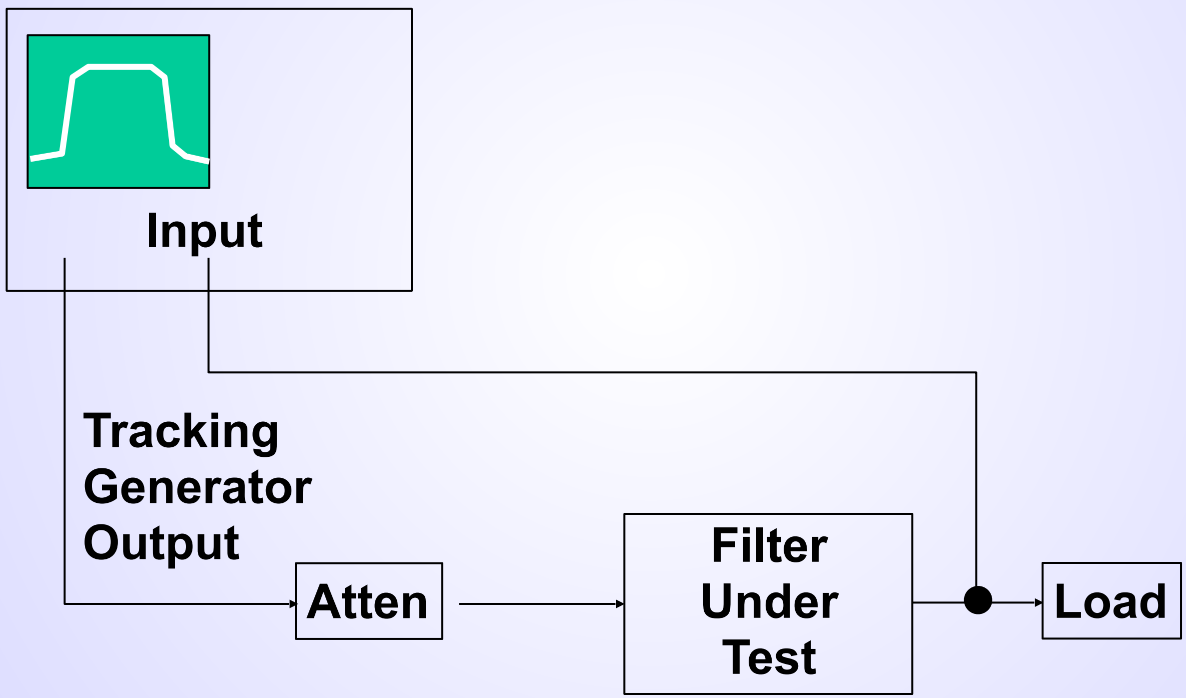


Frequency Domain Measurement

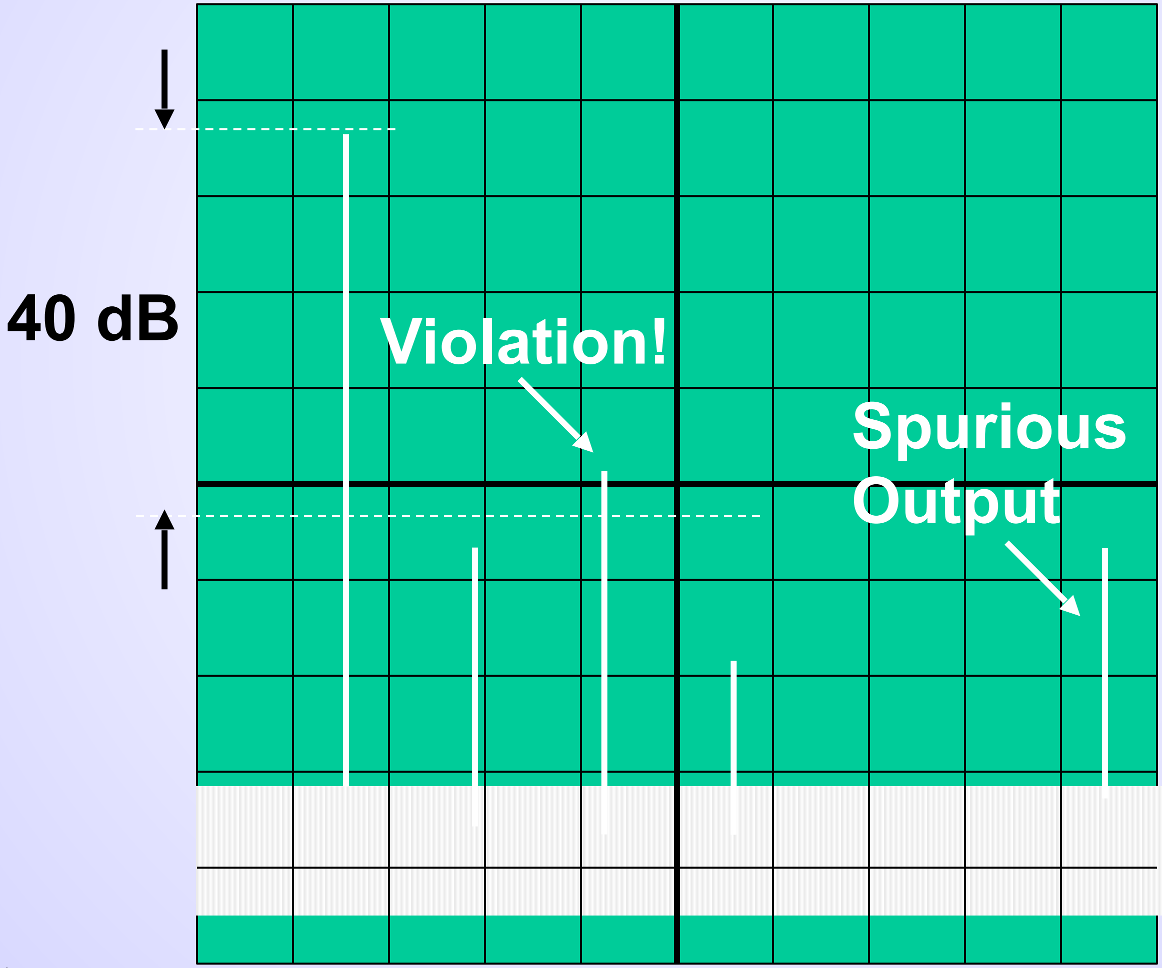


NOTE: Filter BW must be much less than the signal BW for an accurate BW value!

Filter Alignment



Spectrum Checks



Measurement Caveats

- Complex interaction of settings
- Calibration drift of amplitude, frequency
- Sampling effects
- Input is fairly delicate
- Too many decimal points displayed

Emptor Caveats

- Blown or partially-blown inputs
- Usually long past last calibration
  - Amplitude scale non-linearities
  - Passband tilt or shift
- Tracking generator noise
- High noise floor

Network Analyzers

Network Analyzers

- Has nothing to do with computer networks
- Compares magnitude and phase across a two-port device
- Calculates useful values based on those measurements
  - Gain/Phase plots
  - S-parameters
  - Complex impedance

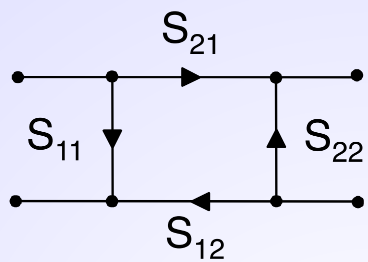
Vector Network Analyzer by TAPR & Ten-Tec

July/August 2004 issue of QEX Magazine

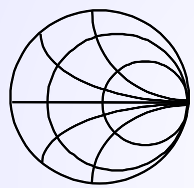
1 MHz to 100 MHz
0.1 dB amplitude
1 degree phase
USB interface
Display & Analysis
via PC software

The Need for Both Magnitude and Phase

1. Complete characterization of linear networks

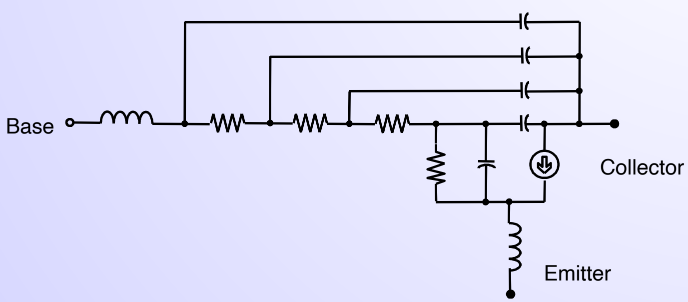


2. Complex impedance needed to design matching circuits

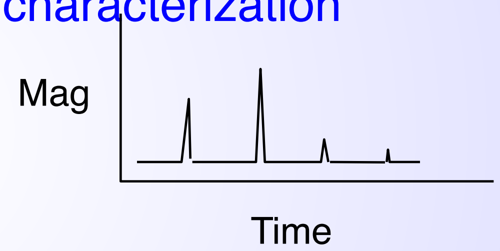


3. Complex values needed for device modeling

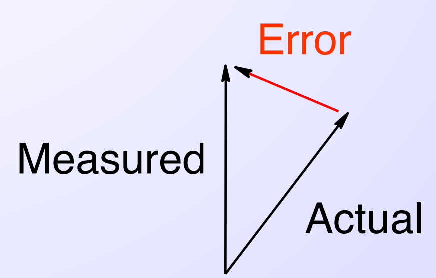
High-frequency transistor model



4. Time-domain characterization

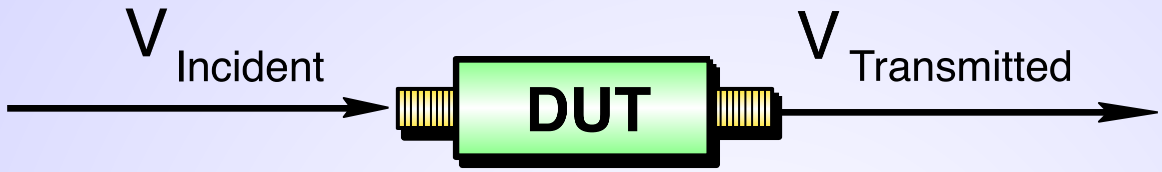


5. Vector-error correction



From "Network Analyzer Basics" by Agilent Technologies

Transmission Parameters



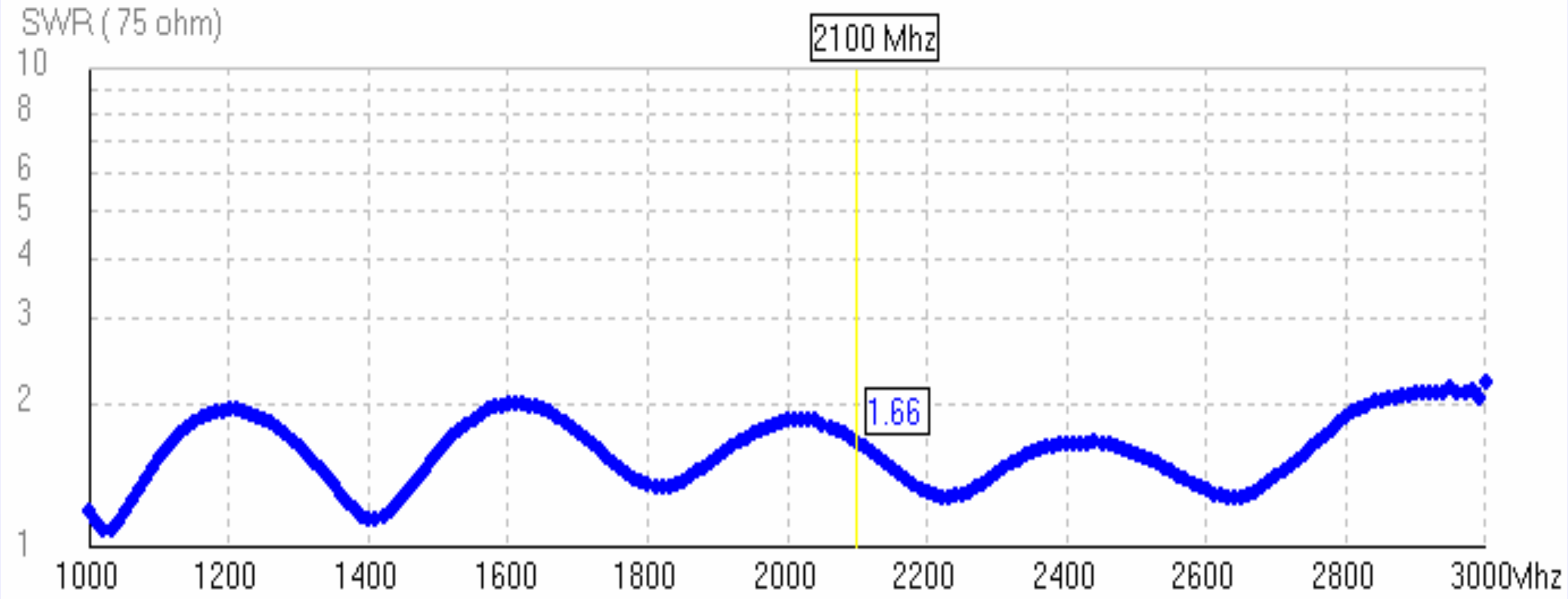
$$\text{Transmission Coefficient} = T = \frac{V_{Transmitted}}{V_{Incident}} = \tau\angle\phi$$

$$\text{Insertion Loss (dB)} = -20\,\text{Log}\left|\frac{V_{Trans}}{V_{Inc}}\right| = -20 \log \tau$$

$$\text{Gain (dB)} = 20\,\text{Log}\left|\frac{V_{Trans}}{V_{Inc}}\right| = 20 \log \tau$$

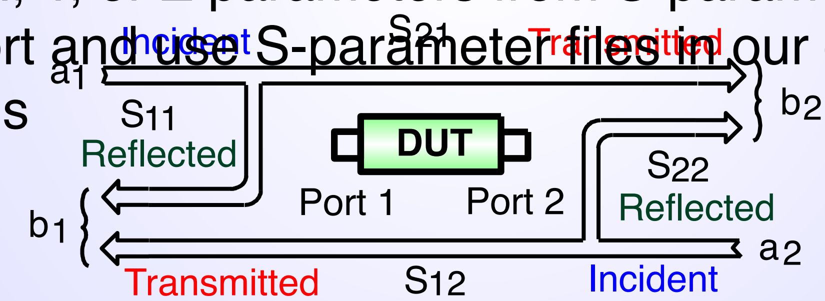
From "Network Analyzer Basics" by Agilent Technologies

Antenna Testing



Why Use S-Parameters?

- relatively easy to **obtain** at high frequencies
  - measure voltage traveling waves with a vector network analyzer
  - don't need shorts/opens which can cause active devices to oscillate or self-destruct
- relate to **familiar** measurements (gain, loss, reflection coefficient ...)
- can **cascade** S-parameters of multiple devices to predict system performance
- can **compute** H, Y, or Z parameters from S-parameters if desired
- can easily import and use S-parameter files in our **electronic-simulation** tools



$$b_1 = S_{11}a_1 + S_{12}a_2$$

$$b_2 = S_{21}a_1 + S_{22}a_2$$

From “Network Analyzer Basics” by Agilent Technologies

Equating S-Parameters with Common Measurement Terms

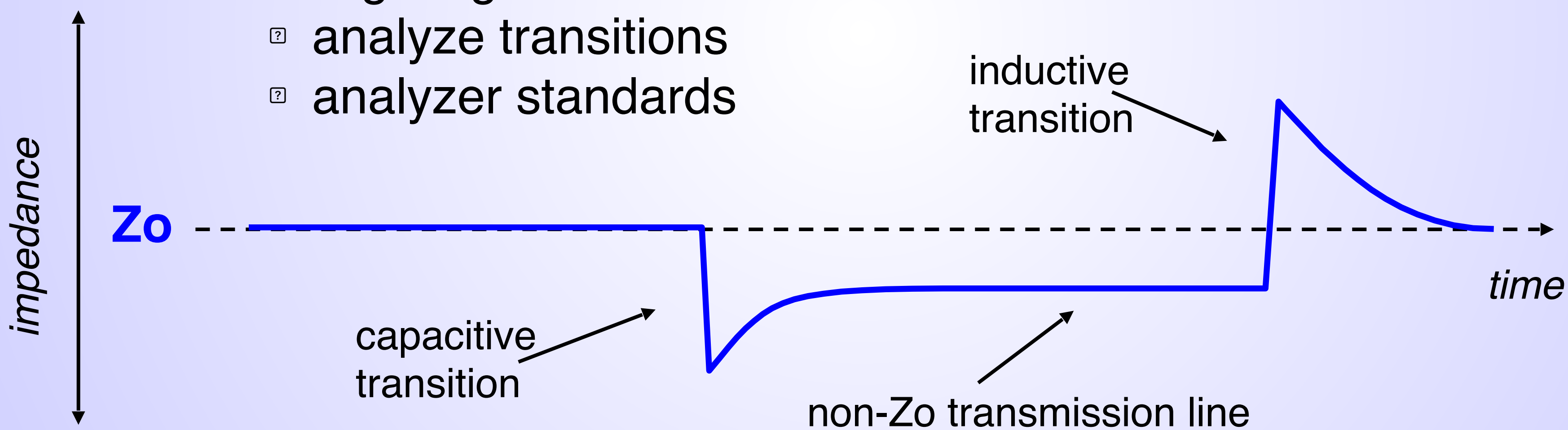
S11 = forward reflection coefficient ***(input match)***
S22 = reverse reflection coefficient ***(output match)***
S21 = forward transmission coefficient ***(gain or loss)***
S12 = reverse transmission coefficient ***(isolation)***

Remember, S-parameters are inherently complex, linear quantities -- however, we often express them in a log-magnitude format

From "Network Analyzer Basics" by Agilent Technologies

Time-Domain Reflectometry (TDR)

- What is TDR?
  - time-domain reflectometry
  - analyze impedance versus time
  - distinguish between inductive and capacitive transitions
- With gating:
  - analyze transitions
  - analyzer standards



From “Network Analyzer Basics” by Agilent Technologies

Measurement Caveats

- Complex interaction of settings
- Unfamiliarity masks errors
- Transmission line effects
- Inputs are fairly delicate

Emptor Caveats

- Blown or partially-blown inputs
- Usually long past last calibration
  – Amplitude scale non-linearities
  – Passband tilt or shift
- Calibration accessories usually lost
  – EXPENSIVE to replace

Resources

On-Line Resources

- Agilent “Educator’s Corner” http://www.educatorscorner.com
  - An Introduction to RF Signal, Noise and Distortion Measurements in the Frequency Domain
  - The Fundamentals of Signal Analysis, AN 243
  - 8 Hints for Making Better Measurements Using Analog RF Signal Generators, AN 1306-1
  - among others…
- RF Cafe - http://www.rfcafe.com
- Web EE Tutorials
  - http://www.web-ee.com/primers/Tutorials.htm#Power%20Conversion

ARRL Resources

- ARRL Handbook & Antenna Book
- Technical Information Service
- ARRL Lab Procedures
  - http://p1k.arrl.org/~ehare/testproc/testproc.pdf
- International Microwave Handbook (publ. by RSGB and ARRL)

Conclusion

- Good stuff out there…IF
  – you take the time to learn how to use it
  – you take the time to learn how not to use it
- Get PC savvy since instrumentation is headed in that direction
- Clubs and friends can share the goodies
- Lots of resources to help you learn!

Thank You!